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Laparoscopic Aortofemoral Bypass

Initial Experience in an Animal Model

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Objective

The study objective was to evaluate the feasibility of laparoscopic aortofemoral bypass in a porcine model.

Summary Background Data

Laparoscopic techniques have been applied to numerous general and thoracic surgical procedures. Their application to vascular surgery has been virtually nonexistent. Open surgery for aortoiliac occlusive disease is accompanied by significant morbidity rates, and minimally invasive procedures have the disadvantage of reduced patency rates. Laparoscopic aortofemoral replacement has the theoretical advantage of long-term patency with reduced postoperative complications.

Methods

Between January and September 1993, laparoscopic surgery was performed on 16 pigs: 6 underwent transperitoneal laparoscopic aortic dissection and vessel control alone; 7 underwent complete transperitoneal laparoscopic aortofemoral bypass; and 3 underwent a retroperitoneal approach. The aortic anastomosis was performed using a combination of sutures and titanium clips in an end-to-side fashion in five pigs, and a custom-made nonsutured graft was secured with use of an end-to-end method in five pigs. Femoral anastomoses were performed with the standard open technique.

Results

Technical success was achieved in all 10 animals and with no major complications. Mean blood loss was 20 ml (range, 5–50 ml), and mean operative time was 2.45 hours (range, 2–4 hrs). On aortic-clamp release, 2 of the end-to-side anastomoses required additional sutures to stop bleeding between oversized staples, and 2 of the end-to-end anastomoses required additional ties to reinforce loose ties. All 10 grafts and anastomoses were patent and free of leaks after completion of the procedure.

Conclusions

Laparoscopic aortofemoral bypass is technically feasible in a porcine model. Further experimental work with new instrumentation and technical refinement will make laparoscopic surgery feasible for the treatment of vascular disease in humans.

Occlusive disease of the distal aortic and iliac arteries can be treated with aortofemoral grafts, extra-anatomic reconstruction, endarterectomy, or angioplasty with and without stents. These procedures have variable 5-year patency rates and associated complications.[1] Abdominal procedures result in mortality rates of 1% to 8% and are associated with significant morbidity rates but 5-year patency rates of 90%.[2,3] Angioplasty is less invasive and results in fewer complications but is not always technically feasible, and the results are generally less durable than that of bypasses.[4] Laparoscopic aortofemoral graft insertion for occlusive disease has the theoretical advantage of reducing postoperative morbidity with preservation of durable long-term patency.

Laparoscopic surgery is generally preferred by patients and surgeons because of reduced postoperative complications and shorter hospital stay. Cholecystectomies are preferentially performed by this method, and surgeons in other branches of surgery have been eager to develop laparoscopic techniques for their procedures.[5] There has been some interest in its use in vascular surgery, but the demands of operating on major vessels have so far prevented assimilation into clinical practice.

Furthermore, criticism has been directed at the adoption of these procedures in humans without sufficient development of techniques, instruments, and evaluation of outcome. Thus, before any new procedure are used in humans, an animal model must be used to perfect and establish limitations of the technique. Accordingly, in June 1992, we initiated this study by formulating a list of potential problems and issues that we would have to overcome during the study and postulated some solutions (Table 1). With this list in mind, we evaluated the feasibility of laparoscopic aortofemoral bypass in a porcine model between January and September 1993.

Table 1.

Problems/Issues	Possible Solutions
1. Exposure	
Approach	Transperitoneal *vs.* Retroperitoneal
Port placement	5–6 ports: 2 for surgeon, 2 for assistant surgeon, 1 for camera, 1 for retraction/suction
Bowel retraction	Trendelenburg position
	Retroperitoneal approach
	Endobowel bag
	Endoharp/endoretractor
2. Personnel	4 people: surgeon, assistant surgeon, camera person, retraction/suction/irrigation person
3. Discussion	Electrocautery scissors
	Endoforceps
	Endo-right angled clamp
4. Control of aorta	Rumel tourniquets
	Intra-aortic balloon
	Vascular endoclamp
5. Control of lumbars	Endoclips/clip applier
	Sutures
6. Control of major/minor bleeders	Vascular endoclamp
	Emergency bulldog clamp
	Endoclips/clip applier
	Electrocautery
	Sutures
	Suction/irrigation
	Direct pressure
7. Graft material	Dacron *vs.* Gore-Tex, knitted *vs.* woven, bifurcated *vs.* straight
8. Anastomosis	
Aorta	End-to-end *vs.* end-to-side
	Continuous *vs.* interrupted suture
	Suture *vs.* clips
	Stent/clasp
Femoral artery	Standard open end-to-side

MATERIALS AND METHODS

Sixteen female pigs weighing 120 to 150 lb were used in this series with the approval of the Animal Research Committee. Anesthesia was induced with xylazine and ketamine and maintained with isoflurane and oxygen through an endotracheal tube. Intravenous fluid replacement with lactated Ringer's solution was maintained throughout the operation with continuous pulse and blood pressure monitoring.

Personnel consisted of the primary surgeon, standing at the right or left of the operating table; a camera operator at the head; and one or two assistant surgeons on the other side of the table. Two video screens were used, one at either end of the table.

Two approaches to the infrarenal abdominal aorta were investigated: transperitoneal and retroperitoneal.

Transperitoneal Approach

A carbon dioxide pneumoperitoneum at 12 to 15 mm Hg was provided after the insertion of a central umbilical 10-mm port. Four laparoscopic 10-mm ports were inserted in each quadrant of the abdomen, with the upper ports positioned closer to the center of the abdomen than the lower ports (Fig. 1). During the course of the procedure, 5-mm access ports were used to exteriorize two stay sutures and two slings. The operating table was positioned to place the head down (Trendelenburg position) and lateral tilt to the right. After inspection of the perito-

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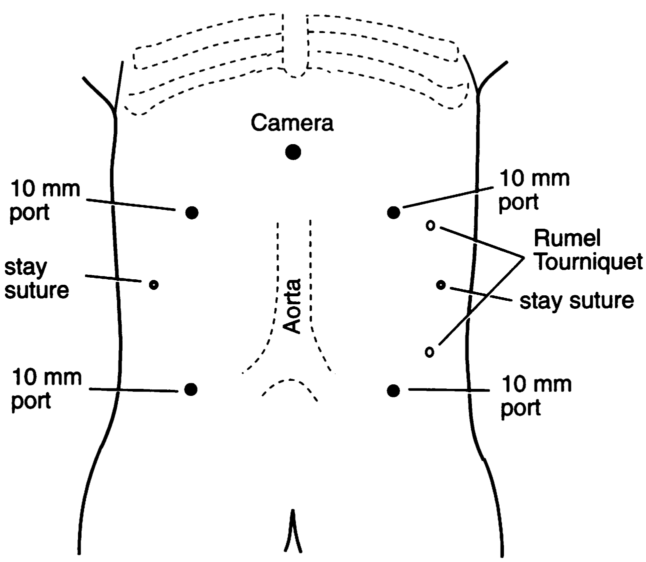

Figure 1. Placement of laparoscopic ports for aortofemoral graft insertion through the transperitoneal approach.

neal cavity, an adjustable three-blade retractor was inserted through the right upper quadrant port to contain the large and small bowel, thereby exposing the midline structures. With the use of standard dissection techniques of traction and counter traction, the transperitoneal lymphatic and fatty tissues were dissected from the aorta using endoscopic scissors with electrocautery. A 6-cm section of the infrarenal aorta was carefully dissected circumferentially. Lumbar vessels were dissected free, ligated with clips, and transected. Care was used to ensure that the renal vessels were not damaged. The proximal and distal ends of the aorta were controlled with umbilical tapes and a rubber catheter (Rumel tourniquet) placed through 5-mm ports in the left lateral abdomen (Fig. 1). The port was removed over the tubing, which was secured by clamps on the outside of the abdomen (Fig. 2). After the administration of 5000 units of heparin intravenously, the tourniquets were used to occlude the aorta proximally and distally (Fig. 2).

In two animals, an intraluminal triple balloon catheter (Ideas for Medicine Inc., Tampa, FL) was tested as a safety net to back up the Rumel tourniquets for aortic control (Fig. 3). This catheter was inserted under fluoroscopic control through the left carotid artery and positioned such that the middle balloon was just below the renal arteries. The middle and distal balloons were inflated to control the aorta, and the proximal balloon was left deflated to be used only as a backup if the middle balloon ruptured or failed.

Retroperitoneal Approach

Pigs were positioned on the operating table on their right side. After a cut-down to the retroperitoneal space was made on the left side, a customized balloon dissector was filled with saline pressurized at 150 mm Hg to create a cavity into which a 10-mm port could be inserted and secured. Carbon dioxide inflation expanded the retroperitoneal space and the remaining ports were inserted: one below the left 12th rib in the midaxillary line, one above the iliac crest, and three in the flank (Fig. 4). The left kidney was visualized and the aorta was then dissected out in a similar fashion to the transperitoneal approach (Fig. 5).

Two different types of proximal anastomosis were performed in the animals, as described below.

End-to-Side Anastomosis

A 2.5-cm longitudinal arteriotomy was made in the anterior portion of the aorta with a #11 scalpel and angled "Potts-like" scissors. Blood remaining in the vessel was irrigated and suctioned. Two stay sutures were placed in the lateral borders of the arteriotomy with use of laparoscopic suture techniques, and the free ends were passed out of the abdomen through stab incisions made between the quadrant access points. In a similar way to the Rumel tourniquets, the stay sutures were held by external clamps (Fig. 2).

A 6-mm tubular stretch PTFE Gore-Tex graft (W.L. Gore & Associates, Flagstaff, AZ) was cut at an angle to match the arteriotomy. A 4-0 double-arm Ethibond suture on RB-1 needles (EMS; Ethicon, Cincinnati, OH)

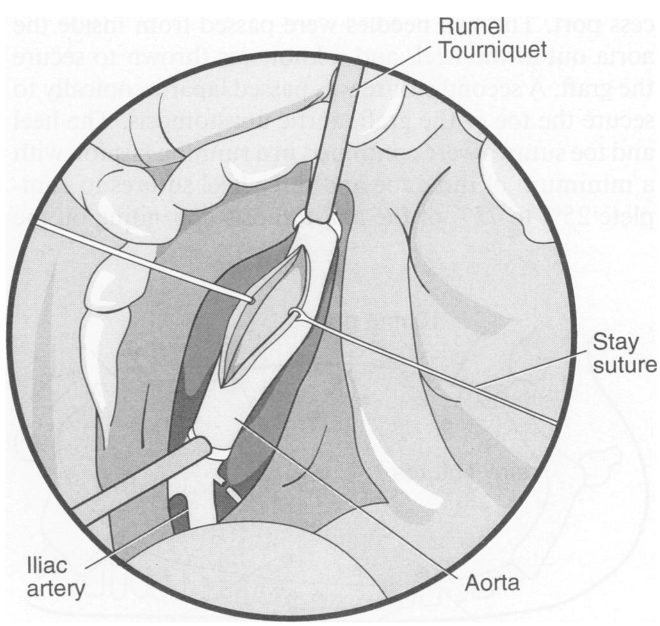

Figure 2. Representation of the appearance of the aorta after dissection from the surrounding transperitoneal tissue. The vessel has been occluded proximally and distally by Rumel tourniquets and passed through the abdominal wall, and the vessel has been opened before suture. Note the transected lumbar vessel.

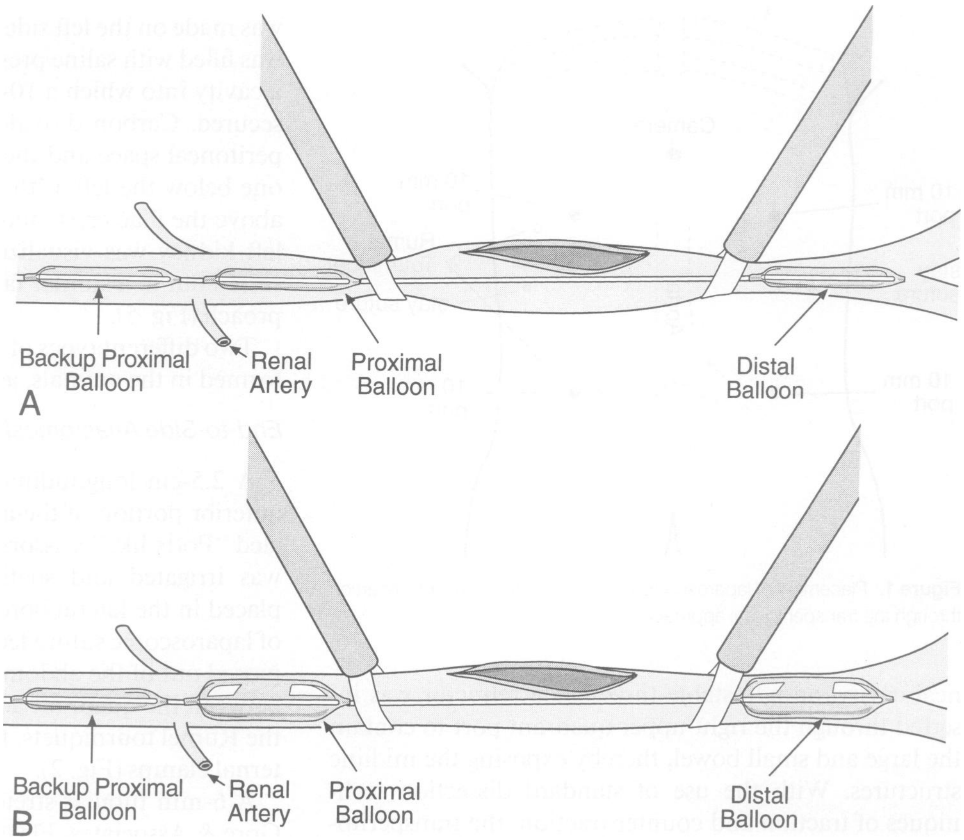

Figure 3. (a) Representation of the Rumel tourniquets placed to control the aortic blood flow with the intra-aortic balloon catheter in place as a safety backup in the event of a catastrophic bleed. (b) Representation of the intra-aortic balloon catheter at work with the distal and proximal balloons inflated to control the aortic flow. If one of these balloons fails to control the bleeder, then the backup proximal balloon in sequence can be inflated to isolate the bleeder.

was passed through the graft, and both graft and suture were then introduced through the left lower quadrant access port. The two needles were passed from inside the aorta out at the heel, and a knot was thrown to secure the graft. A second suture was passed laparoscopically to secure the toe of the graft–aortic anastomosis. The heel and toe sutures were continued in a running fashion with a minimum of three toe and three heel sutures to complete 25% to 75% of the anastomosis depending on the skill and patience of the surgeon on that particular day. The rest of the anastomosis was completed by using an endoscopic multifeed stapler (EMS, Ethicon). The anastomosis was tested by release of the sling tourniquets,

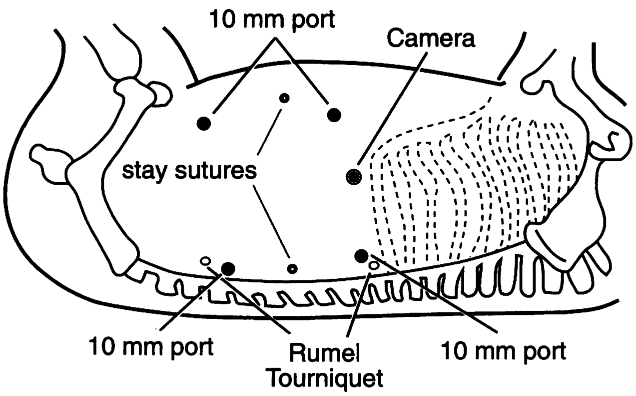

Figure 4. Placement of laparoscopic ports for aortofemoral graft insertion with use of the retroperitoneal approach.

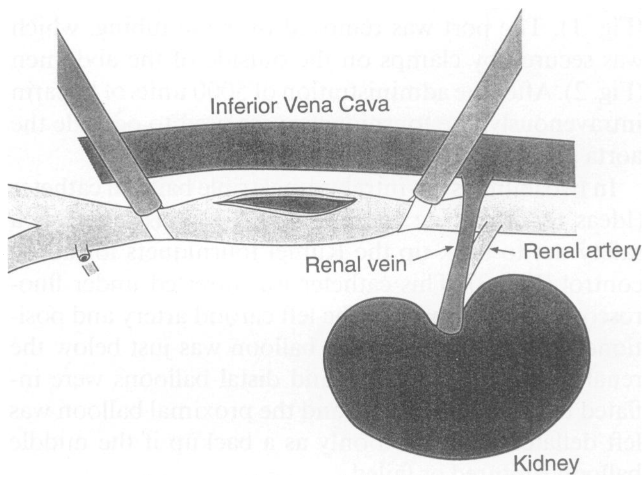

Figure 5. Representation of the appearance of the aorta after dissection from the surrounding retroperitoneal tissue. The vessel has been occluded proximally and distally by Rumel tourniquets, and the vessel has been opened before suture. Note the left kidney, renal artery and vein, inferior vena cava, and transected lumbar vessel.

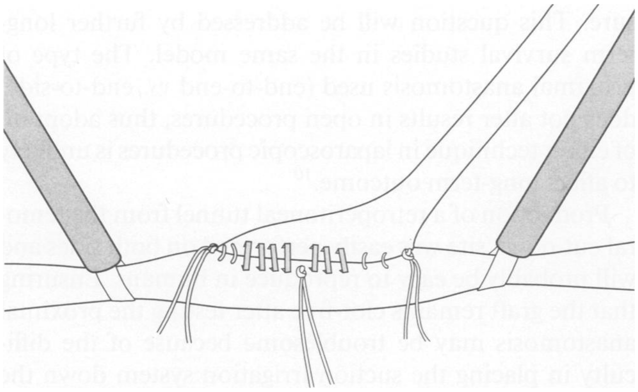

Figure 6. Representation of the suture/clip end-to-side anastomosis of stretch PTFE graft and aorta. The sutures have been passed through the majority of the anastomosis and the residual defects are closed with clips.

and any defects were corrected by sutures or clips (Fig. 6).

End-to-End Anastomosis

An aortic graft was custom-made by attaching it to a connector with a protruding lip (in-house and by W.L. Gore & Associates). After transection of the proximal aorta, the connector was inserted into the lumen and secured twice by a 2-0 silk tie around the vessel so that the lip prevented distal displacement of the graft.

Femoral Anastomosis

For all animals, the left common femoral artery was exposed by an open dissection. After control of the vessels with slings, a long clamp was passed anatomically in a retroperitoneal direction into the peritoneal cavity to retrieve the aortic graft. During this tunneling, the pneumoperitoneum was temporarily lost until the retroperitoneal tissue collapsed around the graft. The graft was cut and anastomosed to the common femoral artery using 6-0 Prolene in a standard open fashion. Before closure of the final suture, the graft was vented by release of the tourniquet. After completion of the femoral anastomosis, the bypass graft was palpated for a pulse, and a 20-gauge needle was inserted in the hood of the femoral anastomosis to document flow in the graft.

Harvest

An open laparotomy was performed immediately after completion of the procedure. The aortic and femoral anastomoses were inspected directly. Then the entire graft, including both anastomoses, was excised *en bloc* to inspect the inside of the graft and anastomoses, looking for any technical defects. After the harvest, the animals were killed with standard euthanasia solutions.

RESULTS

Among the 16 pigs, the first 6 underwent dissection of the infrarenal aorta and both iliac arteries by the transperitoneal approach alone. The next 10 consecutive animals underwent the full procedure as described in the Materials and Methods section. Three of these animals underwent an end-to-end and four an end-to-side anastomosis via the transperitoneal approach. The remaining three animals underwent operation with use of the retroperitoneal approach, two with end-to-end and one with end-to-side anastomosis.

Technical success was achieved in all animals, with a mean operating time of 2.45 hours (range, 2–4 hours). On aortic clamp release, two of the end-to-side anastomoses required additional sutures to stop bleeding between oversized staples, and two of the end-to-end anastomoses required additional ties to reinforce loose ties. Estimated blood loss was 5 to 50 ml (mean, 20 ml). At the time the pigs were killed, all grafts were patent without anastomotic leaks or stenosis.

Only one complication occurred when a small hole was made inadvertently with the electrocautery scissors in the inferior vena cava of one pig. This was successfully controlled with direct pressure.

DISCUSSION

Laparoscopic transperitoneal and/or retroperitoneal aortofemoral graft placement is technically possible in a pig model. The time needed is comparable to that of an open operation in humans, and the procedure is not associated with a high operative complication or conversion rate. The use of this type of procedure in humans has been reported previously with laparoscopic dissection followed by standard open anastomosis.[6] Additionally, laparoscopic intra-abdominal vascular procedures have been performed to clip and ligate the splenic vessel but without anastomoses or reconstruction.[7,8] In the current study we report, to the best of our knowledge, the first graft replacement series performed entirely with use of the laparoscopic method.

The pig is an ideal model for laparoscopic aortofemoral graft placement because its retroperitoneal tissue is similar to that in humans, with much adipose tissue, adherent fibrous tissue, and adjacent bowel. Disadvantages of its use include small vessel size and redundant colon, and the small-bowel mesentery in pigs is longer than in humans, thus allowing for easier retraction of the intestines. The short mesenteric attachment in humans may make retroperitoneal dissection, as opposed to transperitoneal, the optimal choice. For this reason, the retroperitoneal approach was used in the latest operations. Other models, such as the dog model, were considered, but the aorta was too easy to dissect, thus making the model too unlikely to be translated to use in humans.

Four access ports and one camera port were sufficient to enable adequate dissection and graft placement during the transperitoneal approach, although two to four smaller ostia were required to place the slings and stay sutures. The total length of incision in both approaches was less than that required for an open operation, and the positioning of the ports, as has been demonstrated in laparoscopic colon resections, should not compromise postoperative ventilatory movements.[9]

Control of hemorrhage is probably the main factor that limits adoption of laparoscopic vascular graft placement. The small volume of blood lost during the current study procedures was probably due in part to the method of dissection used and the ability to use occluding slings in the presence of normal aortas. Blood loss in humans may be greater because of increased difficulty in dissecting and controlling a diseased aorta, in which the use of Rumel tourniquets may prove to be inadequate and even life threatening. Laparoscopically placed vascular clamps capable of occluding atherosclerotic aortas will need to be developed, and this may increase the number of access ports required. Alternatively, sequential intraaortic balloons placed within the infrarenal aorta, as demonstrated in two of the pigs, might adequately control the aortic flow or at least provide a form of safety backup in the event of a catastrophic bleed, should the Rumel tourniquets or vascular clamps fail (Fig. 3).

This intra-aortic catheter is a double-balloon system that can isolate an aortic bleeder between two inflated balloons. If one of these balloons fails to control the bleeder, then a backup balloon in sequence can be dilated. In the porcine model, we inserted the aortic balloon occluder through the carotid artery for convenience, but in humans, we anticipate inserting the balloon catheter through a high brachial artery or a femoral artery. More research is required to address the efficacy of this method in humans.

The standard sutured proximal anastomosis was possible but technically difficult. Although we could accomplish up to 75% of the anastomosis using sutures, a portion always required staples for completion. In these pigs, the staples worked well, and in two elderly human cadavers with atherosclerotic aortas, these same staples worked even better because of a better match of staple size to the human aorta (Ahn SS, unpublished data, 1992). Nevertheless, in adopting a vascular stapling technique, we must consider the potential difficulty of staple placement in calcified aortic tissue. New vascular staples and clip instruments are being developed.

The end-to-end coupling device was simple to use, but there has been no evidence to show that the anastomosis will hold under long-term sustained systolic blood pressure. This question will be addressed by further long-term survival studies in the same model. The type of proximal anastomosis used (end-to-end *vs.* end-to-side) does not alter results in open procedures, thus adoption of either technique in laparoscopic procedures is unlikely to affect long-term outcome.[10]

Production of a retroperitoneal tunnel from the femoral cut-down site was easily performed on both sides and will probably be easy to reproduce in humans. Ensuring that the graft remains clot-free after testing the proximal anastomosis may be troublesome because of the difficulty in placing the suction irrigation system down the lumen in the confined space of the peritoneum. For this reason, it may not be possible to test the anastomosis until the femoral limb has been exteriorized through the open femoral cut down.

Although theoretically possible, laparoscopic placement of aortic grafts is unlikely to be useful in aneurysm repair, partly because of the potential difficulties in dissection, but mainly because of the advances that have been made in endovascular aortic stenting. However, if the success of these animal operations can be built on, laparoscopic grafting for aortoiliac occlusive disease will be possible, thus maintaining the high patency rates achieved in open procedures without the associated morbidity rates.

Other less-invasive methods of treating aortoiliac occlusive disease are recanalization angioplasties with and without stent insertion.[11] These techniques are in their infancy and have reported patency rates of 87% at 2 years follow-up. In addition, they may be cheaper than open procedures because of the savings in intensive care requirements and hospital stay (Jones L, Braithwaite BD, Farrow R, *et al.*, unpublished data, 1995). What is not known is the 5-year patency of stents and the number of repeat procedures that may be required, along with their attendant costs and risks. Extra-anatomic bypass can be used for those patients unfit for prolonged anesthesia and laparotomy, but this procedure is associated with inferior patency rates when compared with aortofemoral bypass.[12,13] Reduced postoperative complications after laparoscopic surgery might allow some of these patients to be considered for aortofemoral bypass, thus preserving long-term patency. Furthermore, with the increased incidence of blood-borne diseases, a laparoscopic technique provides increased protection for the surgical team. Unfortunately, these advantages may be offset by a reduction in the surgeon's control over the operation, thus this new technique may not prove to be popular.

In conclusion, laparoscopic aortofemoral grafting for occlusive disease may be a useful alternative for patients with aortoiliac occlusive disease and is associated with reduced morbidity rates. We have attempted to overcome problems associated with this procedure (Table 1), but future studies are required to determine optimal laparoscopic technique and instrumentation. The developments made with the use of animal models will invariably lead to techniques and instrumentation that can be used for the minimally invasive management of vascular diseases in humans.

Addendum

On August 2, 1995, the first author successfully performed a laparoscopic aortobifemoral artery bypass in a 48-year-old man with aortoiliac occlusive disease and limb-threatening ischemia, using the principles and steps outlined in this article.

Acknowledgment

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